Back-contacted emitter GaAs solar cells

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A new device structure to improve the performance of concentrator GaAs solar cells is described and the first experimental results are reported. The reason for such an improvement relies on a drastic reduction of the shadowing and series resistance losses based on the possibility of back contacting the emitter region of the solar cell. The experimental results obtained with devices of these types, with a simplified structure, fabricated by liquid phase epitaxy, demonstrate the feasibility and correct operation of the proposed back contact of the emitter of the cells.

The potential efficiency of practical cells of the "classical" heteroface design can be expected to approach 30%.[1,2] This bound is imposed mainly by shadowing and series resistance losses. To reduce these losses, back point contacts have been used successfully for concentrator Si cells and have also been proposed for GaAs cells.[3,4] However, in our opinion, the point emitter approach does not represent a practical solution for GaAs because of the severe requirements posed on the size and density of the emitter dots by the short diffusion lengths of the practical, although good quality, materials.

To overcome such an inconvenience we have proposed a new structure.[1] The proposed back-contacted emitter (BCE) GaAs solar cell consists of a p/n heteroface structure grown on a p^+-type substrate and electrically isolated from it by an insulating layer, as shown in Fig. 1 (this isolation may not be strictly necessary). The p-GaAs emitter is electrically connected to the p^+-GaAs substrate by vertical p-type conductive channels of small diameter and appropriate density. The electrical contact to the p region is thus made on the back side of the substrate. The n-base region consists of a highly conductive n^+ layer to reduce the series resistance, and the photovoltaically active, moderately doped, n layer. The contact to the n-n^+ region can be made on the front side or eventually on the back side as well.

In this solar cell, the minority carriers photogenerated in the photovoltaically active regions, electrons in the emitter, and holes in the base flow vertically and are collected by the p/n junction, as in the classical structure. The majority carriers flow laterally through the emitter region and then vertically through the conductive channels to the p-type substrate. Their contribution to the series resistance is small for well design devices. The majority carriers (electrons) in the n base must flow laterally through the n^+ region, but as this region has no photovoltaic role, it can be heavily doped and therefore the metal contacts can be separated a great distance (in the order of mm) to reduce the obscuration factor without adversely affecting the series resistance.

The main characteristic features of the new device may be summarized as follows: (a) maintains the good intrinsic collection efficiency of the minority carriers characteristic of the heteroface GaAs cell, (b) permits transfer of the current generated in the front emitter region to the substrate and extraction of it through the back contact, (c) permits reduction of the shadowing and series resistance losses due to the fact that the transport of the majority carriers in the base region relies on the high conductivity of a heavily doped, n^+-type back region.

We report here on the experimental results that demonstrate the feasibility of the proposed device. For that, a simplified and no optimized structure, as shown in Fig. 2, was fabricated. An n-GaAs layer was first grown by liquid phase epitaxy (LPE) on a 2×10^{19} cm^{-3} Zn-doped p-GaAs substrate. Then, small diameter holes were chemically etched by sinking the sample, properly covered by a photoresist layout, into a 4 SO_4H_2:H_2O_2:H_2O solution for 5 min. Finally, a window layer was grown by LPE, while Zn was simultaneously diffused from the LPE solution, resulting in the p/n junction and in the p-type connecting channels because of the diffusion along the walls of the etched holes, as shown in Fig. 2. No antireflective coating was deposited on the cells. The scanning electron microscope (SEM) micrograph of Fig. 3 shows the two p/n junctions, which are in parallel but have different diode saturation currents and the vertical conductive channels.

The current voltage characteristics for two samples under one sun (AM1.5 100 mW/cm^2) illumination are shown in Fig. 4. Both devices are 2×2 mm^2 in size and have no metal grid, except for the two external metal bus

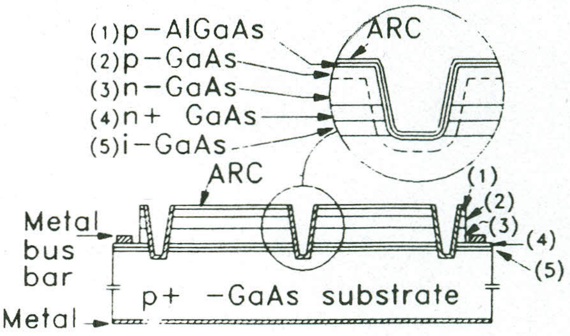

FIG. 1. Structure of the proposed solar cell. All the layers of a complete device are shown.

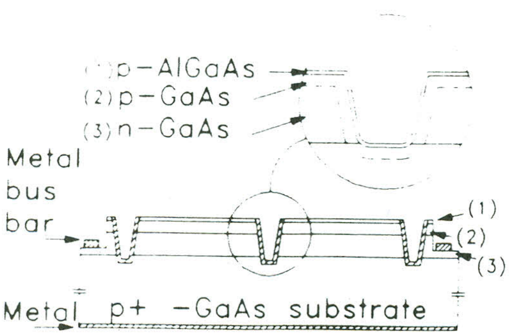

FIG. 2. Simplified structure grown by LPE for the cells reported in this work.

bars for the collection of the current. The measured short-circuit currents of 18.2 and 15.8 mA/cm^2 can be considered acceptable taking into account that no effort was made to optimize the structure (thickness and doping density of the layers) and that no antireflective coating was deposited on the cells. The deposition of a current technology antireflective coating, for example, would increase those currents to about 24 mA/cm^2. The open-circuit voltages, however, are rather low due to the current leakage through the parasitic p/n junction formed between the n base and the p substrate. The influence of this parasitic junction will be negligible in the complete structure of Fig. 1. As a consequence of the rather low currents and voltages the efficiency of these samples (11%–12%) is rather low too. Nevertheless, these results demonstrate the correct operation of the back contact approach and encourage the continuation of the development of finer technology (smaller diameter and higher density of the vertical channels, better isolation between base and substrate to reduce

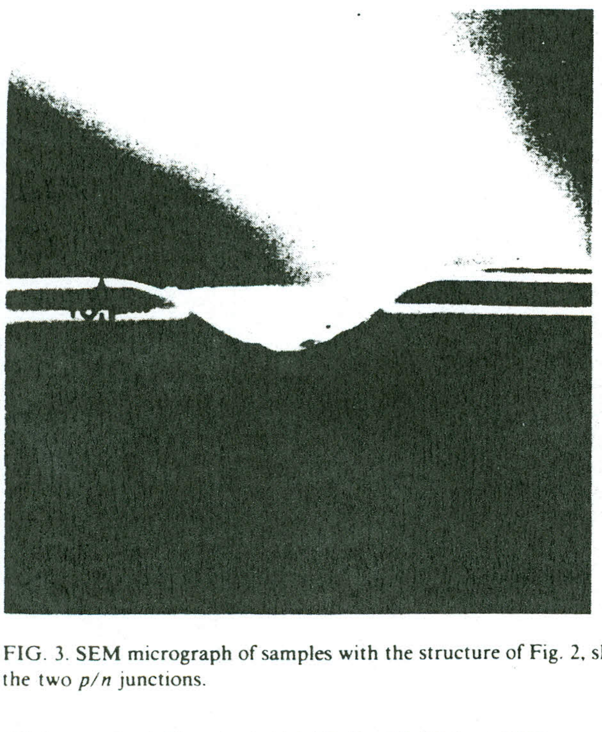

FIG. 3. SEM micrograph of samples with the structure of Fig. 2, showing the two p/n junctions.

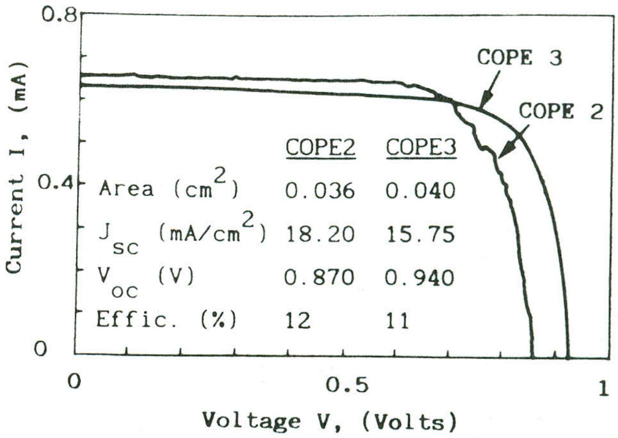

FIG. 4. Measured I-V characteristics of two uncoated samples, under one sun illumination.

the saturation current of the parasitic diode, etc.) devices to increase the efficiency.

As mentioned above, the effort at this first step of the research activity was put in the demonstration of the feasibility and correct operation of the structure. Nevertheless, some calculations have also been made to estimate the potential of these devices. A computer code that calculates the doping levels, the layer widths, and the diameter and density of the vertical conductive channels needed for achieving the maximum efficiency, as a function of the solar concentration, was used for predicting the efficiency of realistic devices. The calculations, made using the photovoltaic parameters reported in Ref. 5, result in a predicted efficiency (28.3%) of the BCE slightly higher than the 28% reported in Ref. 2 for a conventional contacted cell. Series resistance degrades the intrinsic performance of both cells. However, in the BCE cell the main contribution to the series resistance comes from the lateral flow of the majority carriers in the n^+ region. This contribution increases with the sheet resistance of the n^+ layer and with the area of the cell. But, as mentioned before, since the n^+ layer does not play any photovoltaic role, it can be grown to have a sheet resistance as low as possible, with technological feasibility being the only limitation.

In summary, this work describes a new solar cell structure which offers the possibility of improving the performance of concentrator GaAs cells, with present GaAs technology. The reason for such an improvement relies on a drastic reduction of the shadowing and series resistance losses based on the possibility of back contacting the emitter region of the solar cell. Finally, the experimental results we have obtained with devices of this type, with a simplified structure, fabricated by LPE, demonstrate the feasibility and correct operation of the proposed back emitter contact of the cells.

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